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VIBRATIONAL PROPERTIES OF TROPICAL WOODS WITH HISTORICAL USES IN MUSICAL INSTRUMENTS

IRIS BRÉMAUD[1,2], PIERRE CABROLIER[1,2], KAZUYA MINATO, JEAN GÉRARD[3], BERNARD THIBAUT[4]*

[1] Laboratory of Forest Products Circulating Circles, Faculty of Life and Environment Sciences, Kyoto Prefectural University, Kyoto, Japan

[2] Laboratoire de Mécanique et Génie Civil, CNRS, Université Montpellier 2, France.

[3] Production et valorisation des bois tropicaux et méditerranéens, CIRAD, Montpellier, France

[4] Ecologie des Forêts de Guyane, CNRS, Kourou, French Guyana

Abstract

This paper presents a collection of wood species with important uses in musical instruments, in reference to historical and geographical cultural specificities, with ranges of viscoelastic vibrational properties by species. Data combine our experimental characterizations and extensive literature review, gathered in a specific relational database. An overview of vibrational properties' distribution on c.400 species is introduced. Two case studies of wood choices for a given function in different epochs or regions are presented: woods for European historical bows, and woods for idiophone bodies in different continents. Trends are contrasted: very different properties associated to historical changes in the first case; some common features over different regions in the second one.

1. Introduction

Present-day musical instruments are frequently associated to a few « emblematic » wood species for given functions, and these chosen materials participate to the specificities of instruments. Amongst the now archetypal species for Western musical instruments, several are tropical hardwoods, which uses were adopted at different epochs in the last centuries. Well-known examples are Pernambuco (*Caesalpinia echinata*) which started to be used at the end of the XVIIIth century and then became the first choice for violin bows; or Rosewoods (*Dalbergia nigra*, then *D. latifolia*) which became standards for guitar bodies starting from the 19th century. Comparison with other wood species reveals some specific combinations of physical-mechanical properties, especially concerning vibrational properties: the above species are distinguished [10] [14] by atypical values of damping coefficient, a property which is recognized as a key factor for several parts of instruments. Thus, the adoption in the past of "new" wood resource participated to the development of designs and techniques, and to the cultural identity of the resulting instruments. As such, documentation and mechanical characterization of woods employed at different times are important both for the critical study, and for the conservation, restoration or re-construction of these objects of musical heritage.

Of course, the introduction throughout history of "new" or exotic woods in the instrument making culture goes far beyond the two examples introduced above, and many particular species were introduced in this way at different times and for different instruments. A good example of it is the co-evolution in shape/structure and in wood choice for bows, from convex to concave profiles, with different sections, and different chosen species or groups of species.

Another branch of cultural heritage concerns the collections of extra-European instruments, though there is usually quite little historical documentation in this case. Wood choice and its more or less strong permanence represent also in this case an important aspect of the specificity of a given heritage (considering both tangible and intangible heritages).

This paper aims at exploring the diversity of wood vibrational properties, with special reference to tropical woods, in relation with historical or geographical specificities in instruments.

2. Methodology

2.1. Experimental characterizations

* email: iris_bremaud@hotmail.com

Material

Two main samplings of woods were studied. On one hand, woods provided by skilled instrument makers, preferentially off-cuts from pieces from which instruments had been effectively built, and when possible with appreciations. In this paper we will separate the sampling of woods used for bows of early-music quartet and fiddles. This work was run in collaboration with the specialized bow maker Nelly Poidevin (based in Bretagne, France). On the other hand, a wider sampling of many different species, with about 70% tropical ones, was collected, mainly from the well-identified wood stocks from CIRAD (in Montpellier, France). The "bows" sampling covered a total of 250 test specimens belonging to 10 species: 5 temperate ones believed to have been used until Renaissance era and 5 tropical woods used from Baroque –including Snakewood *Brosimum guianense*- to modern eras – including Pernambuco *Caesalpinia echinata*. The "general" sampling contained a total of c.1500 test specimens prepared from 77 species (including 70% tropical hardwoods, 15% temperate hardwoods and 15% softwoods). All studied woods had been stored for several years in ambient conditions before testing.

Methods

Specimens (12×2×150mm, R×T×L) were first dried (in order to reach equilibrium in adsorption) for 48h at 60°C. All measurements were performed after at least 3 weeks stabilization in controlled conditions of 20±1°C and 65±2%RH. Specific gravity and equilibrium moisture content were recorded. Vibrational measurements were made by non-contact forced vibrations of free-free bars (e.g. [12]). Specimens were made to vibrate through a tiny iron piece (weight 15-20 mg) glued on one end, facing an electric magnet. Their displacement was measured using a laser triangulation displacement sensor. Vibration emission and detection were computer-driven using a National Instruments card and a new semi-automated interface that we specifically developed [2] using Labview® Software. E'/ρ was deduced from the first resonant frequency according to the Euler-Bernouilli equation. Damping or loss coefficient –expressed as $\tan\delta$- was measured both through the 'quality factor' Q (bandwidth at half-power; frequency domain) and through logarithmic decrement λ of amplitude after stopping the excitation (time domain). These two methods of determination shall be equivalent. Measurement frequencies were in the range of 200-600 Hz. 3 repetitions were made for each probe and mean error on properties was ≤5%.

2.2. Litterature review and relational database

Data obtained through our above-cited experimental characterizations were much extended by an extensive literature review on wood viscoelastic (i.e. data including damping coefficients) vibrational properties. Data were collected from 30 sources, including some hard-to-obtain ones. Great care has been taken about checking the compatibility of all collected values, especially considering the hygrothermic and frequency conditions of measurements. The data compiled were obtained on woods stabilized in controlled conditions of 20-25°C, at c.65% RH (55-70% RH were accepted but specified) and in the frequency range of 200-1500Hz (data at higher frequencies are listed separately). Basic set of properties includes specific gravity ρ, Young's modulus E, specific dynamic Young's modulus E'/ρ and damping coefficient $\tan\delta$, along the grain (some information on anisotropy ratios were also collected).This "wood vibrational properties" collection contains data for 395 woody species (corresponding to the results of nearly 6000 tests), including 224 tropical hardwoods, 102 temperate hardwoods, 61 softwoods, and 8 monocotyledons.

This collection constitutes the "vibrational properties" datatable in a relational database we created on the specific subjects of "Woods and Instruments Diversity" [3]. The other main datatables include: "uses of woods in instruments" and "woody species taxonomy and information", with additional modules about species conservation and nomenclature (botanical synonyms and common names). All tables are dynamically related together and the whole database includes nearly 700 species, and some information on wood uses in about 160 instruments or the World, also collected from numerous references from several disciplines and languages.

3. General results: an overview of the diversity of wood vibrational properties

The general distributions in specific gravity, Young's modulus and vibrational properties E'/ρ and $\tan\delta$ over the 395 documented wood species are presented in Fig. 1, separating broad categories:

tropical or temperate hardwoods, softwoods, and monocotyledons. The different ranges in specific gravity is a well known fact and confirms that very dense woods (ρ higher than 1) can barely be found outside of tropical hardwoods. This, combined with a higher proportion of E'/ρ, leads to the fact that highest values of Young's modulus can only be found in tropical hardwoods. This point could have been determinant in the case of the application to bows. Finally, the distributions in damping coefficient show that softwoods are centered around the mean values on all woods, while temperate hardwoods are mostly associated to higher than average damping values. Tropical hardwoods have a broad distribution of tanδ, but a high number of species have lower than average damping coefficient, and the lowest values can barely be found for other wood categories. This confirms and extends the statistical validity of some previous statements [9] about the difficulty of finding temperate species with low enough damping to be envisaged as substitutes to tropical species used in some instruments.

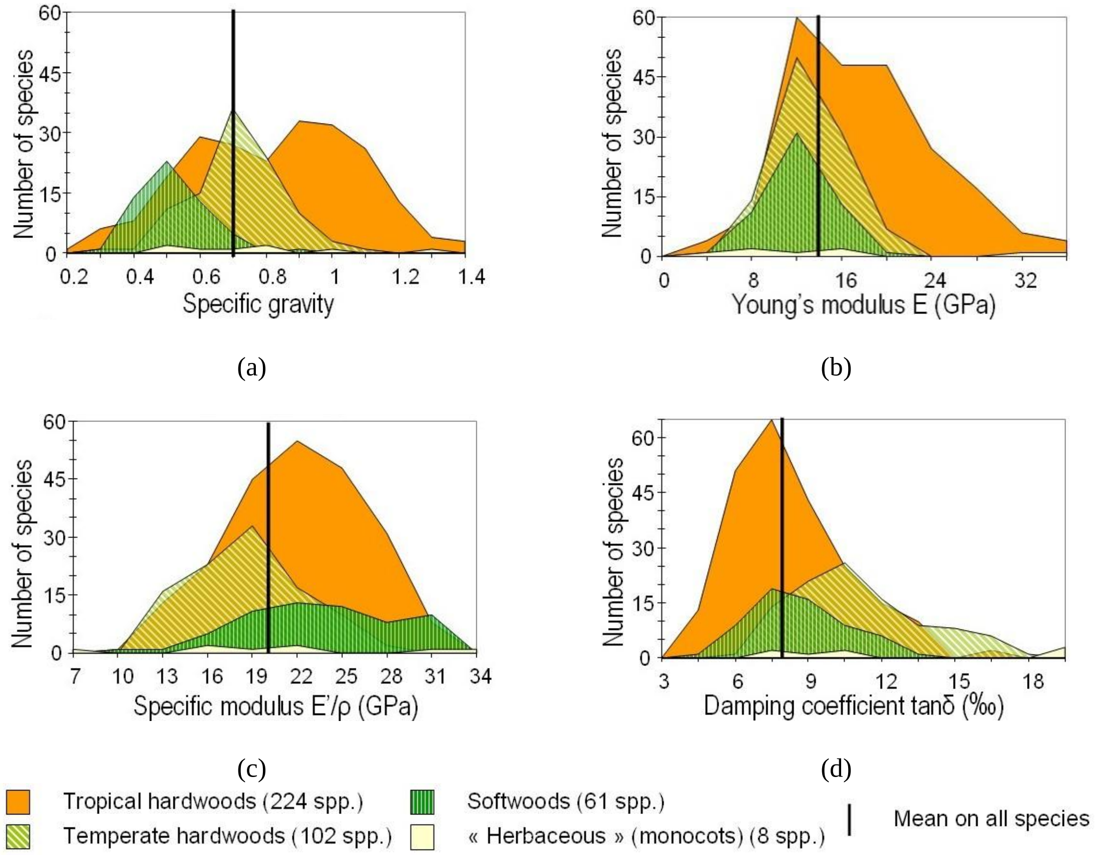


Fig. 1. General distribution of specific gravity (a), Young's modulus (b) and vibrational properties E'/ρ (c) and tanδ (d) over 395 species.

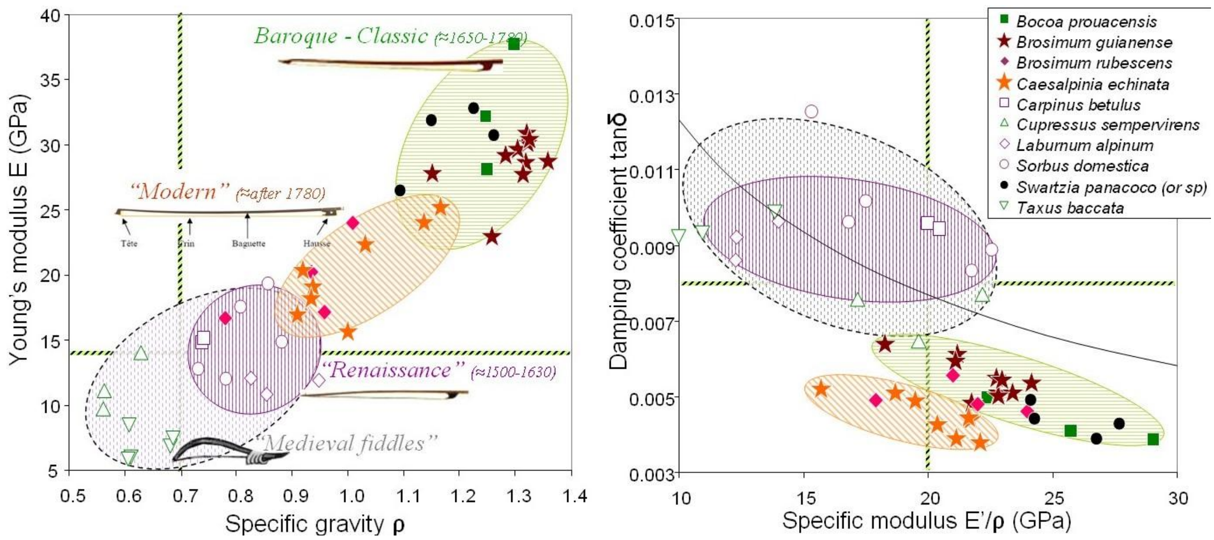
This specificity of very low tanδ for some tropical hardwoods may also be considered from a more fundamental point of view. Previous works have shown that there was a high correlation between tanδ and E'/ρ over different species [13], which resulted from the common effects of microfibril angle [12] and/or natural grain angle [4]. This could define a "standard" relation. If we observe (not shown in Fig. 1) the distribution of the deviations of tanδ to this "standard", the vast majority of woods with "abnormaly low tanδ" are tropical hardwoods, which may be related to their chemical composition, and especially to high extractives contents as it had been demonstrated for some species [2] [11] [14].

4. Two case studies on wood choice at different epochs or regions

4.1. Woods for historical bows in Europe

Violin bows are now firmly associated to Pernambuco (Caesalpinia echinata) wood (although its recent inscription on annex II of CITES might renew the interest for alternative species). This wood started to be tried for bows in the second half of the 18th century, and later became the exclusive standard for highly prized "classical-modern" models of bows. Characterizations of this wood showed an often high Young's modulus (although seldom in the extreme range) and an exceptionally low damping [10]. Woods for bows "should" have adequate specific gravity (for balance and playability), Young's modulus (for stability and holding the tension of hair) and internal damping (in regard to energy dissipation, playability and dynamics). Though, if the "adequate" ranges are associated to those of Pernambuco for classic-modern bows, this may not be so for earlier models (Baroque and Renaissance, and before for Medieval fiddles) which structures are different, and used for different playing modes and musical tastes. Fig. 2 presents the ranges in specific gravity, Young's modulus and vibrational properties (E'/ρ and tanδ) for several species of woods that have been used at different epochs. Historical comments below owe a lot to information provided by N. Poidevin.

The first two observations may be that: i) on the whole studied set of species used for different bows, very wide ranges of properties are recorded; ii) within an ensemble related to different models, ranges are much more focused, and the different ensembles barely overlap. Rather clear wood-structure (and presumably musical trends) associations can be separated.



(a) (b)

Fig. 2. Specific gravity and Young's modulus (a) and vibrational properties E'/ρ and tanδ (b) for woods used in models of bows from different epochs. Authors' experimental data. One mark = mean value of 2-30 samples for one tree and/or "quality". Dashed lines indicate mean values on 395 woods, and plain curve in (b) represents the "normal" relationship between tanδ and E'/ρ [13].

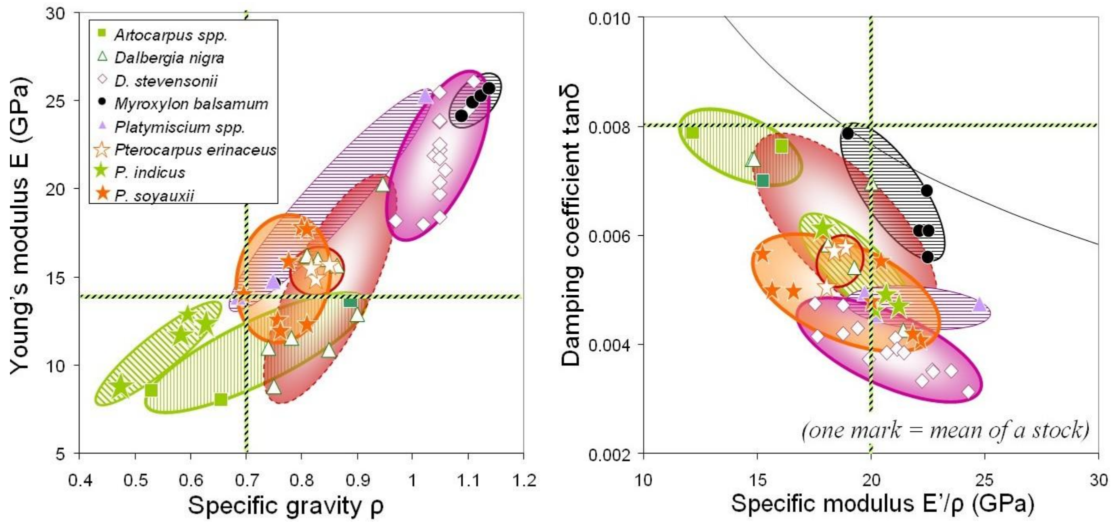
Most hardwoods used from Renaissance are heavier than average and up to extreme values, and have a Young's modulus between average (temperate hardwoods in Renaissance) and exceptionally high (tropical woods in Baroque bows). The South-American woods (including the most often seen Snakewood) adopted in Baroque era had extremely high density and modulus, usually higher than Pernambuco (it shall be noted that Pernambuco was apparently not used in that epoch, although its trade towards Europe was important since 16th century). The introduction of these woods probably allowed the development of the long and thin bow sticks of Baroque era, associated with new trends in playing techniques and places of performances. Slenderness was counter parted by much reducing the curve to maintain stability. These woods used in Baroque bows also have much lower than average damping, which may have provided more playability and dynamics. For the earlier models of bows, damping may not be a critical parameter, or, alternatively, low damping may not be desirable and medium-high values best suited to musical styles and performing conditions; this may also have been simply the result of the difficulty in finding low-damping temperate hardwoods.

From the second half of XVIIIth century, "transitional" bows were made, using both "Baroque" woods, and some lighter species such as *Brosimum rubescens* and Pernambuco, which thereafter became the standard for the classical models. These later models have a concave curve, higher head, and were associated to increasingly virtuoso playing technique, and wider performing rooms. The lower (as compared to Baroque woods) density and exceptionally low damping of Pernambuco may have facilitated very dynamic playing techniques and more powerful emission. The often lower Young's modulus of this wood was dealt with reverse curve in order to keep stiffness and stability.

Finally, it shall be noted that the woods used at different epochs, albeit having very different properties, are adequate to the model there are used for (structure, musical specificity) and material choice seems to involve adaptation rather than maximization. Of course, it is difficult to explore in-depth all facets of this subject in a short article, and a deeper understanding of this subject will ask for mechanical analyses combining structural and material parameters, together with craftsmanship and musicological approaches. Yet, from the "wood" point of view, these results provide an insight into the contribution of chosen material resource (local or imported wood species) to some technical and esthetical developments.

4.2. Woods for vibrating bodies of idiophones through different continents

In the case of "idiophones" (i.e. the primary vibrating part is the main structure of the instrument), studies about "Western" instruments (concert marimbas and xylophones) pointed out that the main woods' physical parameter related to quality appreciation was a very low damping coefficient [1] [8]. Other parameters were a high density, high impact hardness, medium-high specific modulus [9]. It shall be remembered that this type of instruments is somehow of recent introduction in "Western" cultures: about the end of 19th century. Before that, the historical pathways of xylophone-like instruments in tropical regions (Africa, Indonesia, Mesoamerica) have been the subject of several hypotheses, although it seems that the theory of African origin would now prevail. Whatever the historical pathways, we might wonder about the properties of woods traditionally selected for "xylophones" in their several areas of repartition. Another interesting type of wooden idiophone instruments are the slit-drums, which have strong cultural importance in the Pacific regions, and served for long-distance transmission of "spoken" messages in Africa [5] [6]. Fig. 3 presents the ranges in properties of several species used for these idiophones in different continents.



(a) (b)

Fig. 3. Basic properties of woods used for vibrating bodies of xylophones and slit-drums through different continents. Authors' data + literature. Dashed lines and plain curve in (b): see Fig. 2.

The most preferred wood for "Western" concert xylophones is Honduras Rosewood (*Dalbergia stevensonii*), and its damping coefficient is indeed amongst the very lowest not only of the selection above, but on all woods from our collection. There are indications of an early use of Rio Rosewood (*D. nigra*), but apparently its "sound" was considered less bright than Honduran, which is consistent with their respective tanδ values. Interestingly, in Central-America (the bio-geographic range for Honduran Rosewood and several others *Dalbergia spp.*), the preferred woods for the very important traditional marimbas are from an other genus: *Platymiscium spp.* Woods from this genus would deserve more mechanical characterization, but, according to available data, they appear to have also a very low damping, yet sometimes lower density. These species are stated to be “the preferred woods”, while “the most durable and resistant wood is *Myroxylon balsamum*”, but the later has much higher tanδ, so it seems that the traditional choice was firstly based on “acoustic” aspects.

The diversity and cultural importance of “xylophones” and slit-drums in Africa are well-known facts. It has been shown [6] [7] that, the more prominent the purely “acoustic” function of xylophones or slit-drums, the higher the proportion of use of *Pterocarpus spp.* (often *P. soyauxii* in Central Africa), this choice becoming nearly exclusive for the slit-drums for message transmission. While the specific gravity of this species is not very high, its tanδ is amongst the lowest values. In other regions (Mali to Burkina), another species of this genus is the preferred material (*Pterocarpus erinaceus*). Broader characterizations of this wood would be useful, yet it appears that its ranges in properties overlap those of *P. soyauxii*.

Artocarpus spp. are frequently used from SE Asia to Melanesia (Papua-New Guinea to Vanuatu), either for xylophone-like instruments (SE Asia) or slit-drums (the monumental slit-drums of Vanuatu and especially the anthropomorphic slit-drums of Ambrym islands are good examples). It seems that in Vanuatu, *Pterocarpus indicus* is considered as giving a “brighter” sound [personal communication, D. Cardon], which would be consistent with its lower value of tanδ.

This short synthesis indicates that: i) relatively high specific gravity is indeed a frequent feature, but far from being systematic; ii) specific Young’s modulus (related to resonance frequencies for given geometries) is not a key factor: changes in geometry can efficiently deal with actual frequencies; iii) all important woods selected for “xylophones” and/or slit drums are characterized by damping coefficients that are not only lower than the mean values for all kind of woods, but also lower than mean values for woods at equivalent specific modulus E’/ρ [13], whatever the region of the world and local or imported flora. This finding not only supports, but mostly extends the statements of previous authors considering only Western musical instruments [1] [8] [9]. It also suggests that, in the case of these idiophone instruments, the “acoustical” function of the material predominates and leads to rather comparable choices in different continents and cultures.

Another interesting fact is that, apart from the *Artocarpus spp.* (Moraceae), most of the important species presented here belong not only to the same family (Leguminosae-Papilionoideae), but even to the same tribe (Dalbergioideae). Given that, for some *Dalbergia spp.* [14] and *Pterocarpus spp.* [2] [4], extractives were found to be responsible of their exceptionally low damping, we might suspect than there may be some kind of connection between chemotaxonomy, and the empirical selection of these materials for “acoustic” functions throughout different regions of the world.

5. Conclusion

An attempt has been made into clarifying some relations between diversity of wood vibrational properties, and cultural specificities of wood uses in musical instruments. The distribution of properties on 395 species confirmed that very high specific gravity and Young’s modulus can only be found in tropical hardwoods, and gave some statistical evidence that very low damping is also associated to this category of woods. Two cases studies of wood choice for a same function but different historical of geographical cultures were introduced. Woods used for historical models of European bows are rather homogeneous in properties for a given model, and very different between different models. The introduction of imported South-American woods allowed structural –and probably musical- developments. On the contrary, woods traditionally selected for xylophones and slit drums in different continents share some common features, mainly a very low damping coefficient. Several civilizations carefully selected appropriate species from a very diverse local flora. Of course, further interdisciplinary (mechanics, acoustics, wood sciences, musicology, organology, ethnobotany) analyses would be necessary to fully grasp this wide subject. Yet, collected data and documentation may be useful both in the context of documentation for conservation-restoration, and for an approach of the history and ethnology of techniques in the specific domain of wooden musical instruments.

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